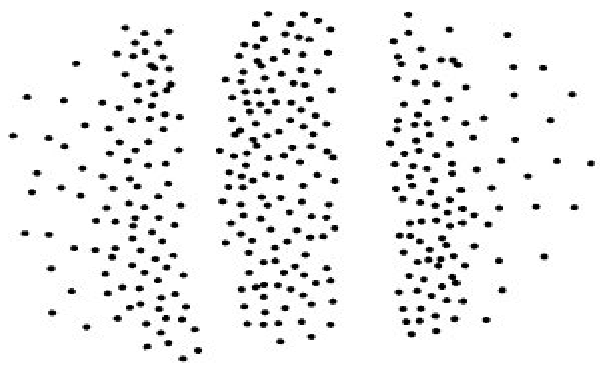
The Double-Slit Experiment – What Really Happens

The following is an attempt to present, in the simplest possible way, a *realistic and local interpretation* of what actually happens in the double slit experiment. In order to clarify what kind of problems are involved, I think the statements are appropriate with which Richard Feynman, who himself made some significant contributions to quantum mechanics, introduces his description of the experiment:

"In this chapter, we shall tackle immediately the basic element of the mysterious behavior in its most strange form. We choose to examine a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery. We cannot explain the mystery in the sense of 'explaining' how it works. We will 'tell' you how it works. In telling you how it works we will have told you about the basic peculiarities of all quantum mechanics." (Feynman, Leighton, Sands, *Lectures on Physics* Vol. 1, 37–2, Addison-Wesley 1965)

Since there are already thousands of descriptions of the experiment, I will limit myself to the absolute minimum of facts and, initially, completely disregard technical details.

We shoot individual electrons from an "electron gun" through a double slit. In doing so, we ensure that in any case only one single electron is on the move in the experimental set-up. Behind the double slit, there is a detector plate that indicates the impact of an electron with a black dot. After a while we observe the following pattern on the detector plate:



So there is ***interference***, and from this follows that the electron must have behaved in a ***wave-like*** manner when it passed through the double slit, since a succession of particles cannot generate this pattern. On the other hand, the observable consequence of the appearance of an electron on the detector plate – the black point – can only be explained by the fact that the electron that hit there is now ***particle-like*** again. The formal relationship between the wave and the observed particle is very simple: the probability that the particle will appear at a certain point results from the square of the wave amplitude at this point.

So ***mathematically*** everything is clear: we determine the equation of the wave and calculate the probabilities. But can we also ***understand*** what is happening there?

What about the wave after the electron appears? Since there was only ***one electron*** on the way and we have now measured ***one electron***, the wave must obviously have disappeared afterwards. But how is that possible? Since its amplitude square gives the probability of the appearance of the electron, the wave must have something to do with this event – somehow it seems to have triggered it. So we actually feel compelled to ascribe ***existence*** to the wave, all the more since the interference also indicates that ***something*** must exist there ***which*** is interfering – but its disappearance prevents us from assuming the existence of the wave.

In addition, we are confronted with the question of ***how*** and ***why*** this strange transition from wave to particle occurs at all.

Let's hear what the fathers of quantum theory have to say about this.

Nils Bohr: "There is no quantum world. There is only an abstract quantum mechanical description. It is wrong to think that the task of physics is to find out how Nature *is*. Physics concerns what we can *say* about Nature." (A. Petersen, *Bulletin of the Atomic Scientist 19*, 12 (1963))

Werner Heisenberg: "In the experiments about atomic events we have to do with things and facts, with phenomena that are just as real as any phenomena in daily life. But the atoms or the elementary particles are not as real; they form a world of potentialities or possibilities rather than one of things or facts." (*Physics and Philosophy*, p. 160, Allen and Unwin, London (1958))

It deserves to be emphasized that Bohr's and Heisenberg's statements do not in the least clarify the situation. They are simply retreat positions. I prefer Richard Feynman's point of view, who calls things by their names and does not gloss over anything:

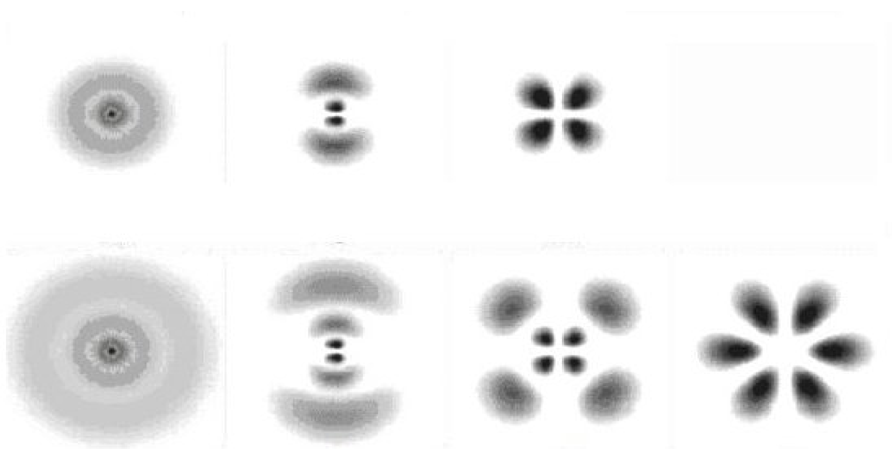
"I think it is safe to say that no one understands quantum mechanics. Do not keep saying to yourself, if you can possibly avoid it, 'but how can it be like that?' because you will go 'down the drain' into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that." (Richard Feynman, *The Character of Physical Law*, Penguin 1992, p. 129)

Even today, after a hundred years of quantum mechanics, there are still physicists, philosophers and interested laypeople who are tormented by the question: *How is that possible?* But actually it's a *cold case*. Since everything is working satisfactorily, almost all physicists have withdrawn to a pragmatic point of view. Anyone who continues to ask questions can choose between a number of "possible worlds" that have been proposed since the introduction of quantum mechanics. But since none of these worlds even remotely solves the problems, I will forego presenting them. I only want to mention one, but actually only because I'm a fan of *fantasy*: the so-called multi-world theory. Here the wave does not disappear, instead it is assumed that at the moment of the measurement (however one may determine this point in time) the universe splits into exactly as many almost identical copies of itself as there are possible measurement results. The variants of the universe then differ from one another only with regard to this result. (Unfortunately, the most important element of the quantum mechanical representation, the *probability*, is lost in this bizarre suggestion.)

But now enough with the status quo – even if it is admittedly quite entertaining. As announced, let us now turn to our real task, the

Answer to the question: What really happens in the double slit experiment?

Let's start with the "electron gun". "Shooting an electron" means: an electron is released from an electron shell. What is an electron shell? Here are some pictures:



Such electron shells are called *orbitals*. They are states of atoms. (If you want to learn more about it and see more beautiful pictures, you can visit Wikipedia or read here, for example.)

With this we have already arrived at the fact that stands in the center of the explanation:

Obviously, the above pictures represent oscillation states of a sphere.

(The gray levels correspond to the squares of the wave amplitudes.)

This means: **Electron shells ARE three-dimensional standing waves.**

In the standard interpretation, the structures depicted above are called "density distributions", i.e. the amplitude square of the wave gives the probability that a (point-like) electron can be found there. (Just as with the running wave after the double slit.)

When an "electron is released" from an orbital, a state with one nodal surface less remains. From our point of view, this means: *A part of the **standing wave** has disengaged and is now on its way as a **running wave**.*

What's next? The electron wave passes through the double slit and then, as expected, it does exactly what waves do: it diverges and interferes with itself. Then it hits the detector plate.

The detector plate, however, is nothing other than the aggregation of an enormous number of objects of the kind shown above. This means: wherever its amplitude is not zero. the *moving electron wave* meets a *standing electron wave*.

And then? Quite simply: then the incoming running wave is added to the local standing waves.

In order to understand what happens next, we have to briefly deal with standing waves. Let us consider, for example, standing air waves in a pipe. They can only exist in a discrete sequence of states, namely in precisely those in which the length of the pipe is an integer multiple of half the wavelength. Only certain tones can therefore be produced with the pipe, the so-called fundamental tone and the associated overtones. If, for example, one blows the pipe so that the fourth overtone can be heard, and then gradually increases the lip tension, then the audible tone does not become gradually higher, but it suddenly "jumps" upwards by a minor third, i.e. to the fifth overtone. *By then, the standing wave in the pipe must already have changed due to the changed excitation conditions – the increasing lip tension –, but the number of wavelengths and nodal areas has remained the same.* Only after the jump the wave in the pipe does have an oscillation area (half a wavelength) and a nodal surface *more* than before.

The same we expect for standing electron waves (the orbitals), i.e. we assume that they only exist in a discrete sequence of states that are defined by the number and type of oscillation areas (or the nodal surfaces between these areas), and only when the excitation conditions change beyond a certain amount, or shall we say: when a certain limit is exceeded, then the standing electron wave will "jump" into the next state – the one with an oscillation area and a nodal surface more – just as it happens when blowing the pipe.

Let us now turn to the double slit experiment again. For the sake of simplicity, let us assume that the standing electron waves that are hit by the running electron wave are all *in the same state*, so that the number and type of their nodal surfaces are the same for all of them. Does that mean that the standing electron waves are all *identical*? Certainly not! It just means that all of them are between the limits to the next higher and the next lower vibration state. Some will be close to the lower limit, many in the middle range, but some will also be so close to the upper limit that a slight push is enough to induce them to "jump" into the next higher state.

(Exactly the same is the case when we hear the same tone from a large number of identical pipes. As we have previously stated, from the identity of the tones does *not* follow that the waves are also identical. Some will be close to a jump to the next lower overtone, others will be close to the next higher overtone. Although the standing waves in the tubes match in the number of their nodes – they are (so to speak) in the "same state" –, they are still *not* identical.)

Now we are sufficiently prepared to understand what is happening:

The extended *running* electron wave hits the *standing* electron waves which lie on the surface of the detector plate. The amplitude of the running wave is very small everywhere – there is only one single "electron" traveling, but perhaps one of the standing electron waves is so close to the limit to the next higher state that the tiny impulse from the running wave is sufficient to trigger the "jump" to this state. In the usual view this would mean: an "electron" has appeared.

What about the rest of the running wave? Well, it *does not disappear*, of course, but adds up to all the other standing electron waves. While this is not yet sufficient for a "jump", it brings all these waves closer to the jump limit and thereby increases the probability of the "appearance of an electron" when the next wave hits or any subsequent one.

With this we have now come to the end of our explanation, and it is time for a few comments and a first, brief summary.

The advantage of the scenario just presented is obviously that it is completely free of all the absurdities that are inevitable both in the standard interpretation and in all alternative variants. In addition, the explanatory scheme can be generalized and leads directly to a local and realistic interpretation of quantum mechanics. (This agrees with Feynman's statement about the double slit experiment mentioned above: "... which has in it the heart of quantum mechanics. In reality, it contains the only mystery.")

However, Bell's proof of non-locality seems to stand in the way of a local interpretation. But it can be shown quite simply that this proof is no longer feasible if the explanatory scheme of the double slit experiment is transferred to the so-called Einstein-Podolski-Rosen scenario.

Admittedly, the model of the "electron shell" which my explanation is based on is incomplete. Above all, two important elements of the quantum mechanical representation are missing: orbital angular momentum and spin. The orbital angular momentum can be supplemented with the idea that the spherical waves shown in the sketch are set in rotation. The integration of the spin requires a somewhat more complex analysis. I have carried out a geometric reconstruction of the quantum mechanical atomic model in the *Concept of Reality*, starting on page 265 (see here).

Is my explanation of the double slit experiment compatible with the established formalism of quantum mechanics? The answer is *yes*. The quantum mechanical prediction – that the probability of the detection of an electron at a specific position is proportional to the amplitude square of the wave that reaches the detector plate – is obviously retained.

To complete the realistic interpretation of the double slit experiment, the following questions must be answered: *What vibrates in electron waves?* – and, since the experiment can also be carried out with "photons" (whereby the explanation remains the same): *What vibrates in photons?* Furthermore: *What do light waves and electron waves have in common, what is the difference between them?* I cannot go into that here. For the desired answers a long mental journey has to be undertaken, back to the *origin of everything* that exists; Only from the fundamental equation that describes the process that creates reality, the necessary conclusions can be drawn.

Ever since I found my explanation of the double slit experiment, I have been concerned with the question of why this explanation – which from the first moment I considered so simple and self-evident that it seemed almost irrefutable to me – has not yet existed. Surely the difficulties that stand in its way are far to be preferred to the absurdities of the usual interpretation!

I believe that the main reason for its lack is to be found in the way physics has evolved. Newtonian physics was based almost entirely on the idea of particles that interact with one another. This idea was so dominant that Christiaan Huygens, for example, had great difficulty in asserting himself with his proof of the wave nature of light. When wave mathematics ultimately established itself on an equal footing with particle mathematics, problems were encountered in the description of the interaction between waves (light) and particles (electrons). The solutions that Einstein and Compton found then led to the so-called wave-particle dualism, which forms the basis of the current interpretation. (I have described this interaction on the basis of the model presented here and have come to the same results as Einstein and Compton (see here and here)).

So it is hard to imagine physics without the idea of "particles". In fact, however, the concept of particles is completely vague. Its only two clear characteristics are *discreetness* and *spatial limitation* of the events – but these are precisely the characteristics of standing waves and the transitions between their states. (Measurement events are always such transitions!)

Ultimately, however, it is also our everyday world experience that suggests the idea of particles. We live in a world of objects that predominantly present themselves to us as solid bodies. The first way into abstraction therefore almost inevitably leads to the assumption of "particles" as basis of reality.

The usual way of presenting the double slit experiment is also completely under the spell of this suggestion. The model idea: "An electron is generated, crosses the double slit, behaves somehow like a wave and finally appears on the detector plate" basically corresponds to the idea of throwing a ball: "Somebody throws a ball, then the ball flies for a while, and finally somebody catches it" – of course apart from the fact that the ball, unlike the electron, always remains a ball and does not temporarily change into a wave-like state along the way.

From the point of view taken here, this model concept is completely unsuitable. Even understanding the electron as an "object" is problematic: is the oscillation area of a standing wave between two nodal surfaces an object? It may seem somehow justified or at least understandable to regard it as an object, and the same applies to the wave diverging after the double slit, which then represents the "electron". But it is completely wrong to assume that the measured electron is in any sense *the same electron* as the one that was generated shortly before: Although – according to our assumptions – the propagating electron wave is the *cause* that somewhere on the detector plate a standing electron wave "jumps" into the next higher state, still the share that the propagating wave has in the newly created oscillation area is negligibly small.

In short: the generated electron *is not* the measured electron.

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